triple-coincidence detection efficiencies as a function of angular separation between detectors for free positron annihilation, $^3S_1$ positronium decay, and forbidden $^1S_0$ positronium decay, respectively; p is the fraction of positrons which forms positronium; and f is the fraction of $^1S_0$ state positronium which undergoes three-quantum decay in violation of C invariance. Thus,

$$(N_{1ox}-N_{Al})/N_{Al} = -p + pK_2(\theta)/K_1(\theta) + 371pfK_3(\theta)/K_1(\theta).$$

The same average value was observed for $(N_{1ox}-N_{Al})/N_{Al}$ in sets of measurements at different angular separations. We assume $K_1(\theta) = K_2(\theta) = K_3(\theta)$, which is reasonable on a physical basis and is not in conflict with the above result.

Six sets of measurements in the described geometry gave values $0.02 \leq (N_{1ox}-N_{Al})/N_{Al} \leq 0.10$. The average results gave a value for $f = 0.0005 \pm 0.0003$. One notes that if C-invariance violation exists in the decay of $^1S_0$ state positronium, there is no a priori reason why it should not exist in the singlet annihilation. Therefore, technically $(N_{1ox}-N_{Al})/N_{Al}$ can be interpreted as a measure of the excess of C-nonconserving decay in the ground-state singlet positronium over similar free singlet decay. From this point of view, one cannot conclude that C conservation was established within the accuracy given but indicates only that C nonconservation, if any, is independent of the radial quantum state.

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IS G PARITY A CONSERVED QUANTUM NUMBER?*

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It is well known that strongly interacting particle systems which have zero strangeness (S) and baryon number (B) are approximate eigenstates of the operator[1] $G = C\exp(i\pi I_2)$, where C represents charge conjugation and I_2 is the "y" component of the isospin $\vec{I}$. Such systems (including single-particle states) are eigenstates of G, I^2, and I_3, and the neutral members are also eigenstates of C. The isospin has integer eigenvalues for these systems, and C and G have eigenvalues ±1 (referred to hereafter simply as $\pm$).

The strong interactions are believed to conserve C and to be invariant with respect to rotations in isospin space. This would imply that transitions between such states, which proceed via the strong interactions, should conserve G, since the operator G performs a 180° rotation about the I_2 axis followed by the operation C.

If we take a completely experimental approach to this question, however, there does not seem to be any clear-cut measure of the extent to which G is conserved, at least when considered in the following spirit. We assume that $I^2 = I_1^2 + I_2^2 + I_3^2$ and C are conserved (along with total angular momentum and parity) and that all eigenstates of I^2, I_3, C, and G are constructed in the usual manner such that the familiar relationship

$$G = C(-1)^I \tag{1}$$

is valid.

There is, in fact, ample evidence that I^2 is conserved for these systems, as evidenced by the nonoccurrence of the decays $\omega^0 \to \pi^+ + \pi^-$, $\varphi \to \pi^+ + \pi^-$, $\eta'(959) \to 3\pi$, and $A_2^\pm \to \pi^+ + \pi^0$. The conservation of I_3, moreover, follows from conservation of charge (Q), since $Q = I_3$ for these systems. Conservation of I^2 and I_3 does not imply conservation of $\vec{I}$, however, since one can conceive of a situation in which the interactions of these systems are invariant with respect to rotations about the I_3 axis only. In such an azimuthally symmetric isospin interaction, G parity need not be conserved. It is the purpose of this note to investigate the experimental evidence that pertains to this question for $S=B=0$ systems.[2]

First we note that under these ground rules (i.e., conservation of I^2, I_3, and C), there can be no tests of G conservation for transitions between neutral systems. This is because both the initial and final states obey (1), and therefore conservation of both I^2 and C implies conservation of G. Conversely, violation of G for neutral → neutral transitions is not allowed.

However, for charged systems (which are not eigenstates of C) the conservation of I^2 does not imply conservation of G. Thus the question of G conservation for charged systems is experimentally testable. This can best be illustrated with an example: Suppose we have a meson (X^0) whose quantum numbers are known to be $J^PI^G=1^-1^-$. The decay $X^+ \to \pi^+ + \pi^0$ is then allowed by conservation of total angular momentum (J), parity (P), and I^2, but it is G forbidden. Thus the existence (nonexistence) of this mode would be good evidence against (for) G conservation.

We now turn to the existing data which might pertain to this question. According to the above arguments we only need consider charged systems.

The rho meson.—The quantum numbers are well established as $J^PI^G=1^-1^+$. The G parity is known to be + since the decay $\rho^0 \to \pi^+ + \pi^-$ with $L=1$ proves that $C=-$. The relation (1) then establishes $G=+$. The observed decay $\rho^+ \to \pi^+ + \pi^0$ is therefore G allowed and does not give us any information on the possible existence of G forbidden decays. The decays $\rho^\pm \to \eta^0 + \pi^\pm$ or $(3\pi)^\pm$, which would violate G invariance, do not seem to be present (data from the Michigan bubble-chamber group indicate a branching ratio of less than 1% for each of these modes), but these might be this small simply from phase-space considerations. Taking the cube of the ratio of the center-of-mass momenta for $\pi\pi$ to $\eta\pi$ decays gives an $\eta\pi$ branching ratio of only 2.3%, for example. Thus, although observation of a reasonably large (say 10%) branching ratio for either of these modes would be good evidence against G conservation, their nonexistence is probably not good evidence in favor of G conservation.

The A_2 meson.—There have been several published reports[3-8] on the existence of the $A_2^\pm$(1310 MeV) meson. The quantum numbers which seem to be fairly well established are $J^PI=2^+1$. The evidence for the A_2^0 is extremely scanty, the only claim for it being a small bump in a $K_1^0K_1^0$ mass spectrum,[4] which would indicate $G=-$. If G is in fact negative, then there does not seem to be much hope of testing G conservation in $A_2^\pm$ decay since the 2π mode is forbidden by I^2, and the other G-nonconserving modes (such as $\omega\pi$) might very well be dominated by the observed G-conserving modes $\rho\pi$, $\eta\pi$, and K^-K^0. If, on the other hand, G is + for the A_2^0, then the $\rho\pi$ mode of the $A_2^\pm$ proves that G is not conserved. In this case the most likely allowed (by I^2+C) modes for the A_2^0 will be $\omega^0\pi^0$, $\eta^0\pi^+\pi^-$, 4π, and $K\bar{K}\pi$, and the A_2^0 width might be much narrower than that of the $A_2^\pm$.[9]

An assignment $G=+$ for the A_2^0 would, in fact, prohibit the production of the A_2^0 by single-particle ($\pi^\pm, \rho^\pm, A_2^\pm$) exchange in $\pi^\pm$-nucleon collisions so this might even explain why the A_2^0 has been so elusive.

It should be mentioned that there is evidence[10] for a $\pi^+\pi^-\pi^0$ resonance around 1300 MeV produced in π^+d collisions. However, it does not seem to be associated with $\rho^\pm\pi^\mp$, and therefore cannot, at present, be considered as the A_2^0. If further data are available to establish $A_2^0 \to \rho^\pm + \pi^\mp$, $K_1^0K_1^0$, or $\eta^0\pi^0$ then the A_2^0 must have $G=-$, in which case, as already pointed out, the $A_2^\pm$ is not likely to shed any light on the question of G conservation.

There exist other inconsistencies[11] in the $K\bar{K}$ and $\eta\pi$ branching ratios of the $A_2^\pm$, but the hypothesis of G nonconservation gives no obvious clarification of these. One possibility would be to let the D meson[12] have $I^G=1^+$ with $J^P=0^-$, 1^+, or 2^-, and let the main mode of the $D^\pm$ be $\rho\pi$. The 1290-MeV $\rho^0\pi^+$ peak observed[6] at 8 GeV could then be due to the D^+ (instead of the A_2), and the absence of the $\eta^0\pi^+$ mode would be explained.

The A_1 and B mesons.—These both have been assigned $I=1$, but their status as states with definite quantum numbers is quite doubtful.[13,14] Their neutral members have not been seen, so even if they are real they do not, at present, offer any good tests of G-parity conservation.

Ways to test G.—The nonconservation of G can be demonstrated by finding charged states that decay into modes of different G, such as $\omega\pi$ and $\rho\pi$ and $\pi\pi$. The proof that G conservation is valid is, perhaps, more difficult. If one could find, for example, an $X^0 \to \eta^0 + \pi^0$ with odd J, then the nonoccurrence of $X^+ \to \pi + \pi$ would be good evidence in favor of G conservation.

There do not seem to be any simple tests for G in $\bar{p}n$ or $\bar{n}p$ interactions since it is not obvious how to prepare initial states of known G for these systems. One possibility would be the comparison of $\bar{p} + p \to \varphi^0 + \pi^0$ with $\bar{p} + n \to \varphi^0 + \pi^-$. These two processes do not have to be identical if G is not conserved.

Conclusion.—We conclude that present data on the strong interactions of $S = B = 0$ systems offer good evidence in favor of I^2 conservation but do not exclude the possibility that G is not conserved.[15] The question of G conservation can be, in principle, subjected to sensitive experimental tests, but whether or not these tests will become available may depend largely on the cooperation of nature.

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QUARK MODEL FOR FORWARD SCATTERING AMPLITUDES

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We should like to point out some remarkable relations which follow from an extremely simple quark-model[1] assumption. These include (a) relations between meson-baryon and baryon-baryon forward-scattering amplitudes which are in good agreement with experiment and which are not obviously obtainable in any other way, and (b) relations for meson-baryon scattering which are also obtainable from higher symmetries. Our basic assumption is that the forward-scattering amplitude for any reaction is simply the sum of all possible contributing two-body quark-quark or quark-antiquark scattering amplitudes.

Consider, for example, π^+P scattering. We denote the proton and neutron by P and N, respectively, and the basic triplet of quarks by p, n, λ, where p, n constitute an isodoublet of strangeness zero and λ is an isosinglet of strangeness -1. The quark constitution of π^+ is $(p\bar{n})$, of P is (ppn). The π^+P forward-scattering amplitude is then given by[2]

$$\begin{aligned}\langle\pi^+P\,|\,\pi^+P\rangle &= \langle(p\bar{n})(ppn)\,|\,(p\bar{n})(ppn)\rangle \\ &= 2\langle pp\,|\,pp\rangle + \langle pn\,|\,pn\rangle + 2\langle\bar{n}p\,|\,\bar{n}p\rangle + \langle\bar{n}n\,|\,\bar{n}n\rangle. \qquad (1)\end{aligned}$$